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COMPARISON OF 50-MILLIBAR GEOPOTENTIALS DERIVED FROM SATELLITE INFRA-RED SPECTROMETER READINGS WITH THOSE DERIVED FROM A SERIES OF ANALYSED CHARTS

By N. R. WATSON and V. BAILEY

SUMMARY

Over the period from June 1974 to May 1975 comparisons were made of 50-mb geopotentials estimated (a) from an analysed chart series and (b) from SIRS data.

Two Vertical Temperature Profile Radiometers (VTPRs) were mounted on each satellite, and ground-controlled switching made it possible for them to be selectively interrogated. It was found that differences between the two estimates (a) and (b) showed marked discontinuities when the alternative VTPRs were switched in, and it was also found that for any one VTPR there was a marked latitudinal variation. The differences showed a marked decrease after the introduction of a new method of SIRS temperature retrieval in March 1975.

INTRODUCTION

During recent years, soundings of the vertical temperature profile of the atmosphere deduced from measurements made by radiometers mounted on satellites have become available. In particular the radiances measured by the Vertical Temperature Profile Radiometers (VTPRs) on board the NOAA series of spacecraft are used to produce the Satellite Infra-red Spectrometer (SIRS) soundings which are distributed on the Global Telecommunication System (McMillin *et alii*, 1973).

This paper reports some results obtained from a comparison of the 50-mb geopotentials obtained from SIRS soundings with those from a chart series, which used radiosonde data only, prepared by the Stratospheric Analysis Group in the High Atmosphere Branch of the Meteorological Office.

METHODS OF COMPARISON

Since April 1974 the Stratospheric Analysis Group have been drawing daily hemispheric 00 GMT charts of the 50-mb geopotential field, using radiosonde data only. The ascents are corrected for known differences between sonde systems, and great emphasis is placed on the continuity of flow patterns in order to produce a series of charts which represent the best available analyses.

The radiosonde network is mainly over land, with occasional island stations or weather ships in the oceanic areas. The SIRS soundings, however, are always made over the sea, and because NOAA spacecraft are in sun-synchronous orbits, the soundings made over a given area occur at approximately the same time every day. Any comparison between 50-mb SIRS and 'sonde' geopotentials must be made near 00 GMT each day in order to minimize the effect of any large-scale changes in the pressure field. Therefore only SIRS soundings within three hours of 00 GMT were used in the comparisons, and this meant that the comparison areas were restricted to the Atlantic and to the western Pacific off Japan.

The SIRS soundings are received as the geopotentials of the standard levels relative to the 1000-mb surface. The 1000–50-mb thicknesses were therefore plotted on the appropriate 00 GMT surface chart to find the 1000-mb geopotential, and simple addition gave the SIRS 50-mb geopotentials. These were then compared with the geopotentials indicated by the analysed 'sonde' charts.

For the 49 occasions when comparisons were made in the 12 months ending May 1975, the average number of SIRS minus 'sonde' differences each day was about 45, with a minimum of 8 and a maximum of 85. For the period 3–10 March 1975 comparisons were made daily.

This method of comparison differs from that used by May (1975) who used SIRS soundings within 175 km of a radiosonde station and within two hours of 00 and 12 GMT.

Results

The variation of the mean SIRS minus 'sonde' geopotential difference during the 12-month period is shown in Figure 1. Of interest are the minimum in early December 1974 and the generally high values from January to March 1975. This could not be explained by any meteorological factor, but when the variability is examined in conjunction with the VTPR instrument in use at the time (shown at the bottom of the figure) a close correlation can be seen between changes of instrument and gross change in the difference. This is most marked in mid December 1974, when Instrument No. 1 on NOAA 3 was replaced by Instrument No. 2. The change is about 25 geopotential decametres, which corresponds to a 3-deg temperature difference in the 1000–50-mb layer. Furthermore, in addition to these gross changes, a slow continuous change of lesser magnitude is apparent in the readings from Instrument No. 1 on NOAA 2.

May (1975) had found a strong latitudinal variation in his SIRS minus 'sonde' differences, so the present data were checked and a similar variation was found. A check was made to see if there was any difference in the latitude variation between comparisons made in the Atlantic area and in the Pacific area. No statistically significant difference was found, so the comparisons from both areas were combined. The mean differences of geopotential for 10° latitude bands from 20° to 70°N are shown in Table I (together with the numbers of observations and the standard errors of the means) and they are also plotted in Figure 2. The annual mean difference is about 10 geopotential decametres, becomes zero at about 60°N, and has a slope of about $-0{\cdot}3$ dam deg^{-1}. This latitudinal variation could lead to erroneous conclusions regarding day-to-day changes in the geopotential difference, if the mean latitude of the day's comparisons changed from one day to the next. In Figure 1 the mean

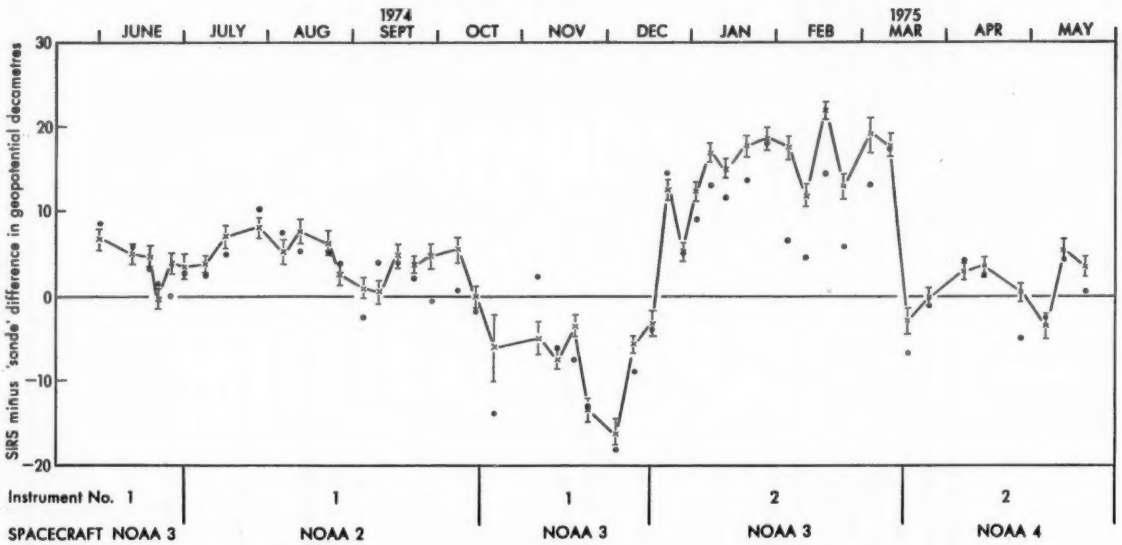

FIGURE 1—VARIATION OF 50-MILLIBAR 'SIRS' MINUS 'SONDE' GEOPOTENTIAL DIFFERENCES FROM JUNE 1974 TO MAY 1975

x differences over all latitudes. Vertical lines indicate standard errors of means.
. differences for 40°–50°N latitude band.

TABLE I—'SIRS' MINUS 'SONDE' GEOPOTENTIAL DIFFERENCES

Latitude (°N)	Annual mean	Standard error	Number of comparisons
	geopotential decametres		
60–70	−1·79	0·98	166
50–60	2·27	0·49	515
40–50	3·36	0·45	590
30–40	8·05	0·45	632
20–30	10·83	0·63	446

geopotential differences for the 40°–50°N latitude band only are also plotted, and, like the mean differences, they vary from one VTPR instrument to another, so confirming the reality of changes with instrument.

The latitudinal variation for the year is a mean over all the instruments used. For the eight-day period from 3 to 10 March 1975, when Instrument No. 2 on NOAA 3 was operational, daily comparisons were carried out, and a latitudinal variation of about −0·45 dam deg^{-1} was found, with a difference increased to 23 geopotential decametres between 20° and 30°N (see Figure 2).

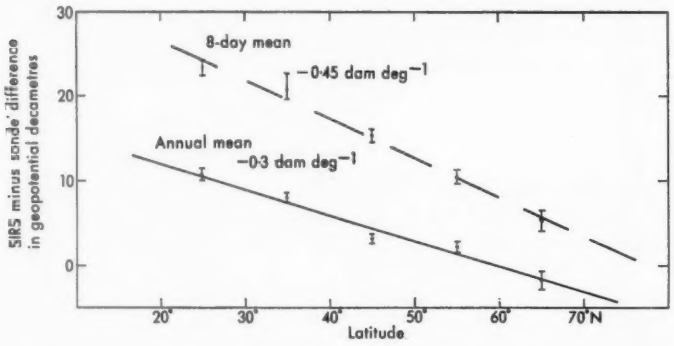

FIGURE 2—VARIATION OF 'SIRS' MINUS 'SONDE' GEOPOTENTIAL DIFFERENCES WITH LATITUDE
Vertical lines indicate standard errors of means.

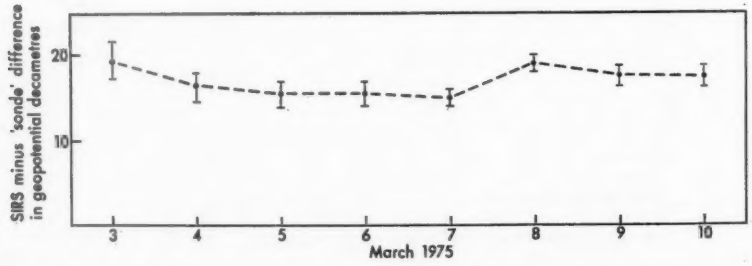

FIGURE 3—EIGHT-DAY VARIATION OF 'SIRS' MINUS 'SONDE' GEOPOTENTIAL DIFFERENCES
Vertical lines indicate standard errors of means.

The daily mean differences during the eight days are shown in Figure 3, together with the standard errors of the means. The daily average during this limited period was 1·5 geopotential decametres, with a maximum change of 4 geopotential decametres.

Conclusions

The results presented show that each VTPR instrument used during the year had a different systematic error, and that for Instrument No. 1 on NOAA 2 there was a gradual change in the error with time. Furthermore, each instrument overestimated tropical stratospheric heights. With no other observations available, the wind field derived from VTPR data would have a westerly component about 15 knots too high in mid latitudes. This would suppress the light easterly wind found in the summer at 50 mb. From a recent publication (Werbowetzki *et alii*, 1975) it appears that the technique of temperature retrieval (and hence also that of geopotential-thickness retrieval) was changed during March 1975. The reduction in SIRS minus 'sonde' difference at that time may have been caused by this change rather than by the introduction of the new instrument. Up to that time, atmospheric temperatures were calculated directly from a knowledge of the 'weighting function' for each channel in the instrument. The weighting function determines the proportion of radiation that reaches the spacecraft from a given level, and it is calculated from the spectral characteristics of CO_2 augmented by laboratory experiments. The systematic differences noted in Figure 1 indicate that there were errors in these weighting functions and perhaps also in the radiometry of each instrument.

Since mid March 1975, however, SIRS thicknesses have been found by using regression equations involving the radiances received in each channel of the instrument. The coefficients used in the equations were calculated from coincident ($\pm$80 km, $\pm$6 hour) radiosonde and VTPR data. These coefficients were progressively updated during 1975 as more coincident data were accumulated.

The new SIRS technique should produce zero geopotential difference between SIRS and sondes, and should minimize the latitudinal effect. The present study is being continued to check whether these improvements actually occur.

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A PRESSURE JUMP AND AN ASSOCIATED SEICHE AT TOBRUK

By D. H. PHILIPS
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SUMMARY

A series of pressure oscillations with one very large, almost instantaneous, jump of 4 mb was observed at Tobruk and El Adem in March 1966 as a cold front approached and passed over these stations. A seiche of amplitude 1·6 m was apparently triggered off in Tobruk Harbour by the disturbances.

INTRODUCTION

Pressure jumps (Grimmer, 1963; Kirk, 1961, 1963a, 1963b, 1963c; Lamb, 1954; Tepper, 1950) particularly those in the Mediterranean area, have been well recorded and described. This article concerns a vigorous pressure jump of 4 mb at El Adem and Tobruk, and an apparently associated seiche in Tobruk Harbour on 25 March 1966.

THE PRESSURE JUMP

The pressure jump was first noticed at El Adem, which is situated about 22 km south of Tobruk in Libya. The duty observer at the Meteorological Office, Royal Air Force El Adem noticed at about 0200 GMT (0400 local time) that the pressure trace on the barograph had jumped upwards by about 4 mb and had immediately returned to its previous level (see Figure 1). He reported the event to Air Traffic Control, and a note was also made in the daily register of meteorological observations.

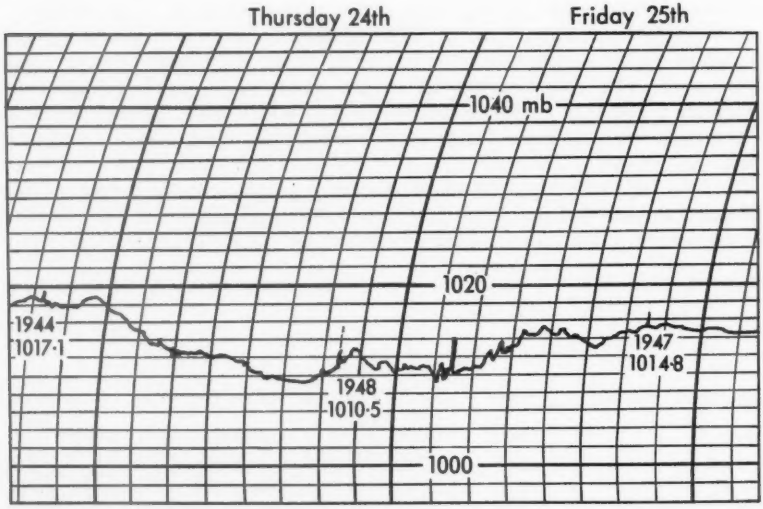

FIGURE 1—DIAGRAMMATIC REPRESENTATION OF BAROGRAPH TRACE AT EL ADEM, 23–25 MARCH 1966

Times are in local time (GMT + 2 hours).

A subsequent examination of the barogram showed that the pressure had been oscillating from about 1600 GMT on the 24th until 1100 GMT on the 25th, and indeed some of these oscillations could be treated as pressure jumps in their own right. The timing of the 4-mb jump seemed to be at about 0220 GMT.

At 0257 GMT a wind shift from 310°/12 kn to 260°/18 kn was recorded in the register. Unfortunately the anemograph was unserviceable and so no detailed wind trace could be analysed. The thermograph trace showed a sharp drop in temperature at about 1630 GMT which was in part caused by the diurnal variation but was also presumably associated with the onset of the pressure oscillations. Two further minor falls in temperature occurred at 2240 GMT and 0310 GMT (see Figure 2).

No thermogram was available from the Tobruk radiosonde station, but the barogram showed a similar pressure jump of about 4 mb at 0200 GMT and an erratic trace from 1500 GMT on the 24th until 1000 GMT on the 25th. Again, some of the oscillations could be treated as pressure jumps (see Figure 3).

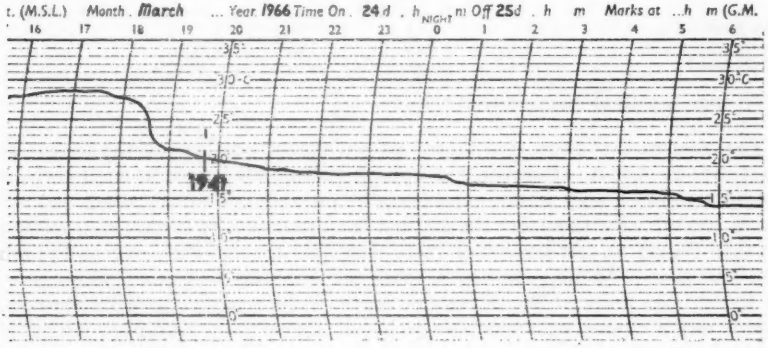

FIGURE 2—DIAGRAMMATIC REPRESENTATION OF THERMOGRAPH TRACE AT EL ADEM, 24–25 MARCH 1966

Times are in local time (GMT + 2 hours).

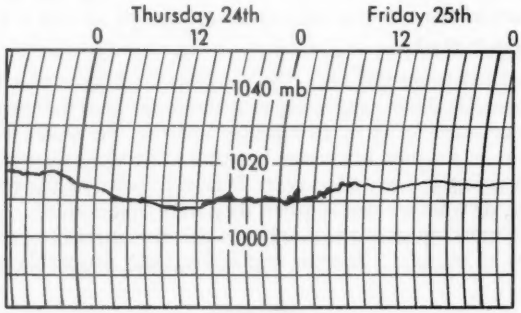

FIGURE 3—DIAGRAMMATIC REPRESENTATION OF BAROGRAPH TRACE AT TOBRUK, 24–25 MARCH 1966

Times are in GMT.

The synoptic situation

The synoptic surface charts (Servizio Meteorologico Italiano, 1966) (Figures 4–6) show that a cold front approached El Adem and Tobruk from the west-north-west, passing over Tobruk at about 0200 GMT, and over El Adem about 20 minutes later. A small low was identified to the south-west of El Adem at 0600 GMT on the 25th.

El Adem's observations, from 0058 to 0431 GMT, were as follows:

Time (GMT)	0058	0159	0245	0354	0431
Total cloud amount	8/8	8/8	8/8	8/8	8/8
Wind direction	340°	330°	310°	020°	350°
Wind speed (kn)	20	12	12	08	10
Visibility (km)	3·2	3·2	3·7	3·7	5·6
Present weather	Sand raised by wind	Slight rain	Rain in past hour	Rain in past hour	Slight rain
Past weather	Cloudy	Cloudy	Rain	Cloudy	Cloudy
Cloud	8/8 As at 12 000 ft	4/8 Ac at 8000 ft 8/8 As at 12 000 ft	3/8 Ac at 9000 ft 8/8 As at 12 000 ft	6/8 As at 10 000 ft 8/8 Cs at 20 000 ft	6/8 As at 10 000 ft 8/8 Cs at 20 000 ft
Dry bulb (°C)	17	17	16	15	—
Dew-point (°C)	13	13	14	14	—
QNH (mb)	1010·4	1011·4	1011·8	1010·4	—

QNH approximates to mean-sea-level pressure.

The observations show that there was not much 'weather' on the front—at least over El Adem. However, the Tobruk radiosonde ascent at 0000 GMT on the 25th shows a very warm, conditionally unstable layer from about 900 mb up to 600 mb. By 1200 GMT the air had been replaced by cooler, more stable air (see Figure 7). At 0000 GMT there were two tropopauses, one at 173 mb and the other at 86 mb, whereas at 1200 GMT there was only one tropopause—at 88 mb; the point at 260 mb could, however, be regarded as a tropopause. There was a strong west-south-westerly jet stream with maximum winds of 230°/151 kn at 12 400 gpm and 250°/162 kn at 11 280 gpm at 0000 and 1200 GMT respectively. The 850-mb contour lines and isotherms on the 0000 GMT upper-air chart are somewhat out of phase with those at 500 mb (see Figures 8 and 9). The 300-mb analysis chart for 0000 GMT on the 25th and the isallobaric chart for 1800 GMT on the 24th have been included in order to give a more complete picture of the synoptic situation (see Figures 10 and 11).

A seiche in Tobruk Harbour

At about 0915 GMT on the 25th, the sergeant on duty at the RAF Marine Section in Tobruk Harbour rang to say that the water level there was fluctuating by 1·6 metres or more in 15 to 20 minutes and that the water was flowing at speeds of up to 10 kn past his boats, but that there were no waves. This, he said, had been going on since 0600 GMT. It is not clear whether the oscillations started at 0600, or whether that is when they were first noticed. A check made later on in the morning gave the amplitude as 1·6 m, and the period, between high waters, as 24 minutes. The rise and fall was still detectable two days later.

Discussion

Kirk (1963b) suggests that an explanation of a pressure jump could be:

(a) a sharp drop in tropopause height, and

(b) the occurrence of out-of-phase relationships at different levels.

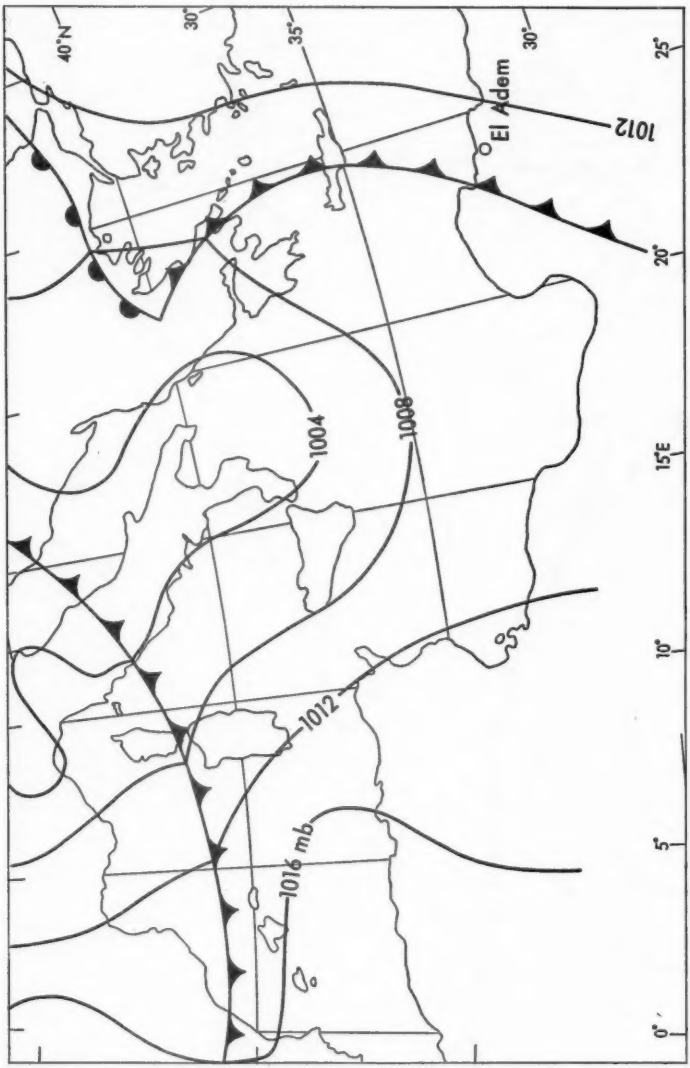

FIGURE 4—SURFACE ANALYSIS FOR 18 GMT, 24 MARCH 1966

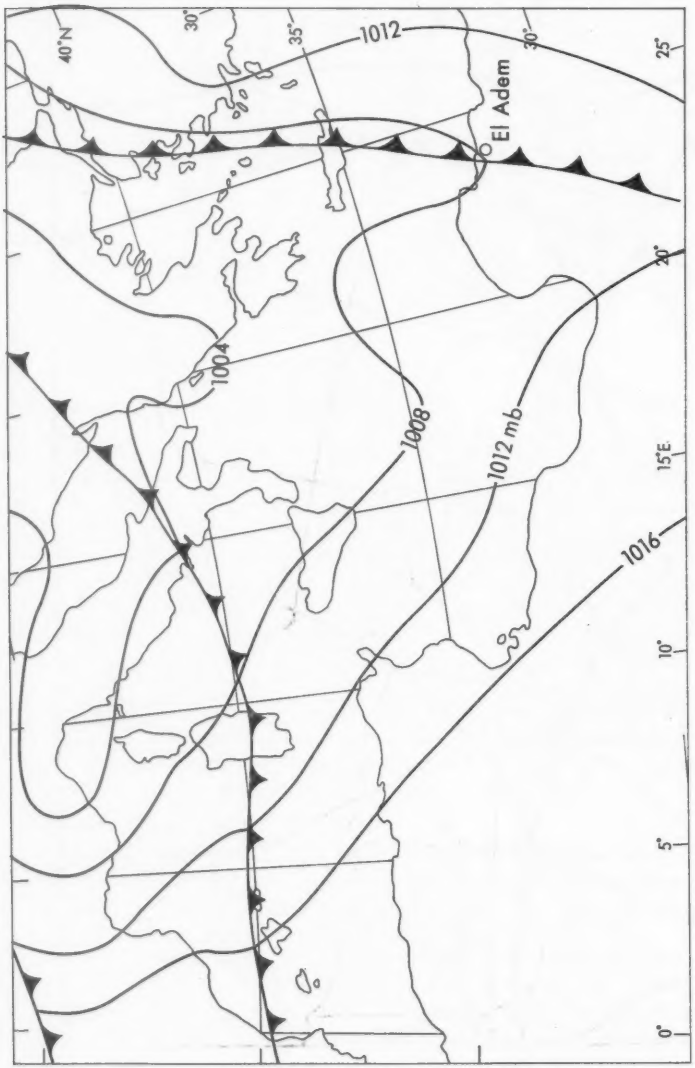

FIGURE 5—SURFACE ANALYSIS FOR 00 GMT, 25 MARCH 1966

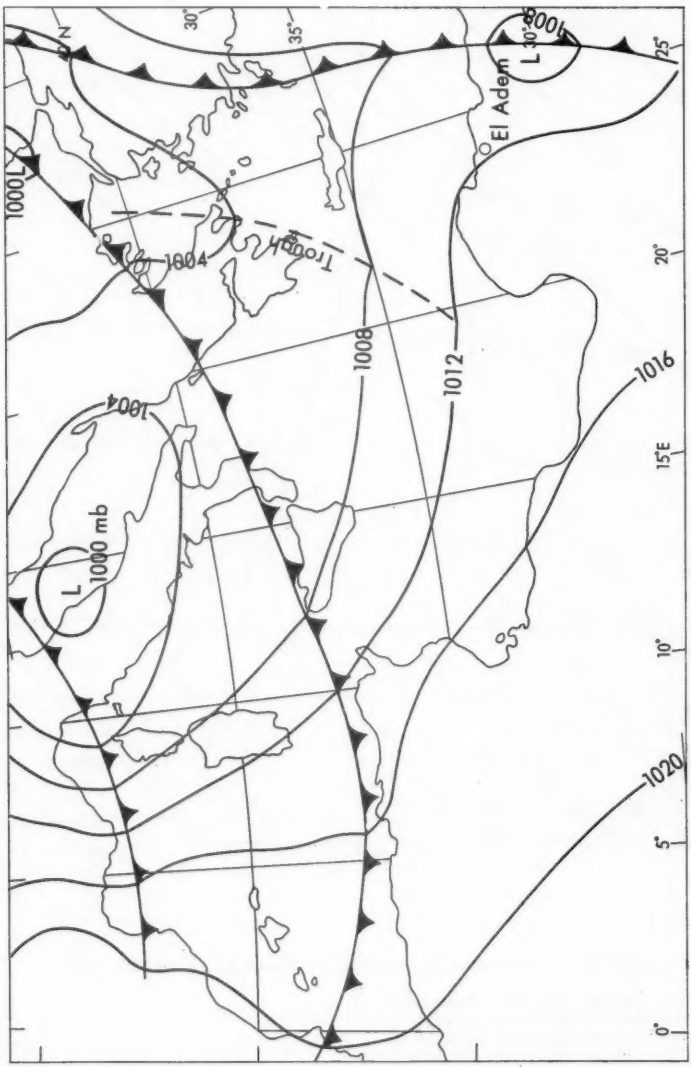

FIGURE 6—SURFACE ANALYSIS FOR 06 GMT, 25 MARCH 1966

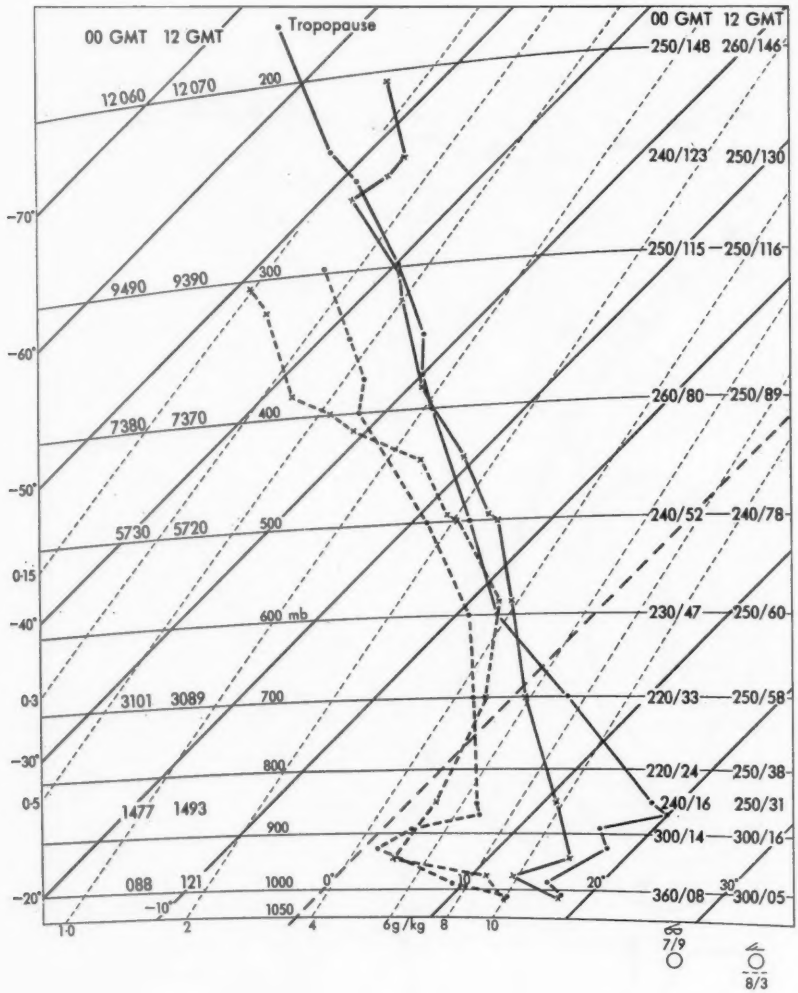

FIGURE 7—RADIOSONDE ASCENTS AT TOBRUK, 25 MARCH 1966

· ——— · 00 GMT dry-bulb temperature.
· - - - · 00 GMT dew-point temperature.
x —— x 12 GMT dry-bulb temperature.
x - - - x 12 GMT dew-point temperature.

Geopotentials in geopotential metres are shown at the left-hand side and winds in degrees true and knots at the right-hand side.

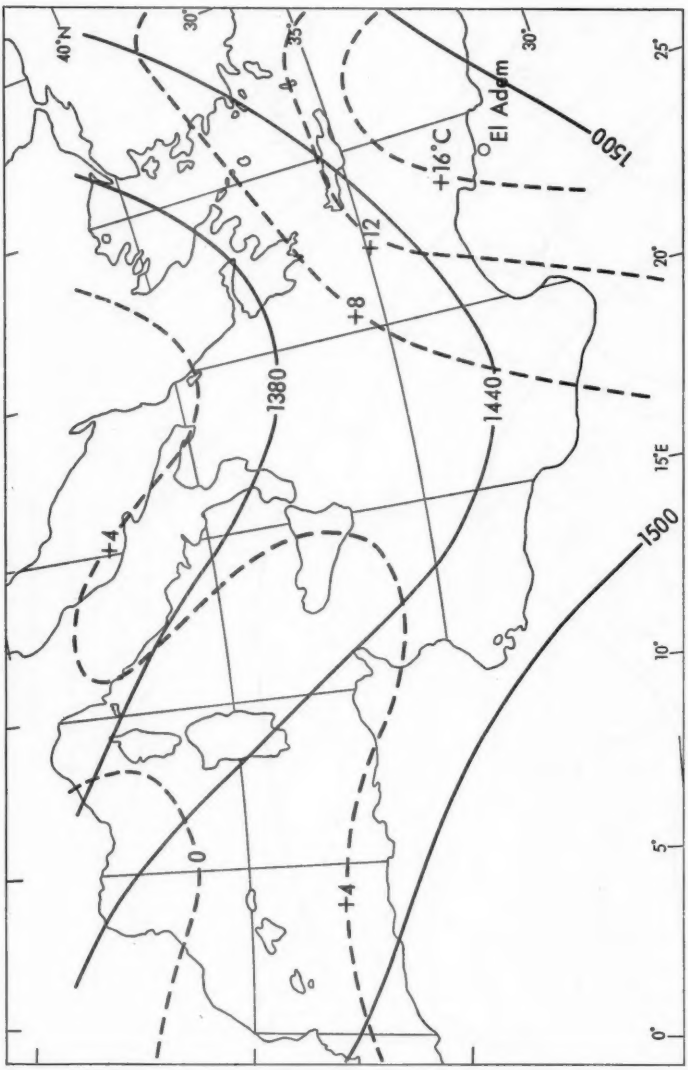

FIGURE 8—850-mb ANALYSIS FOR 00 GMT, 25 MARCH 1966

——— heights in geopotential metres.
- - - - temperatures in degrees Celsius.

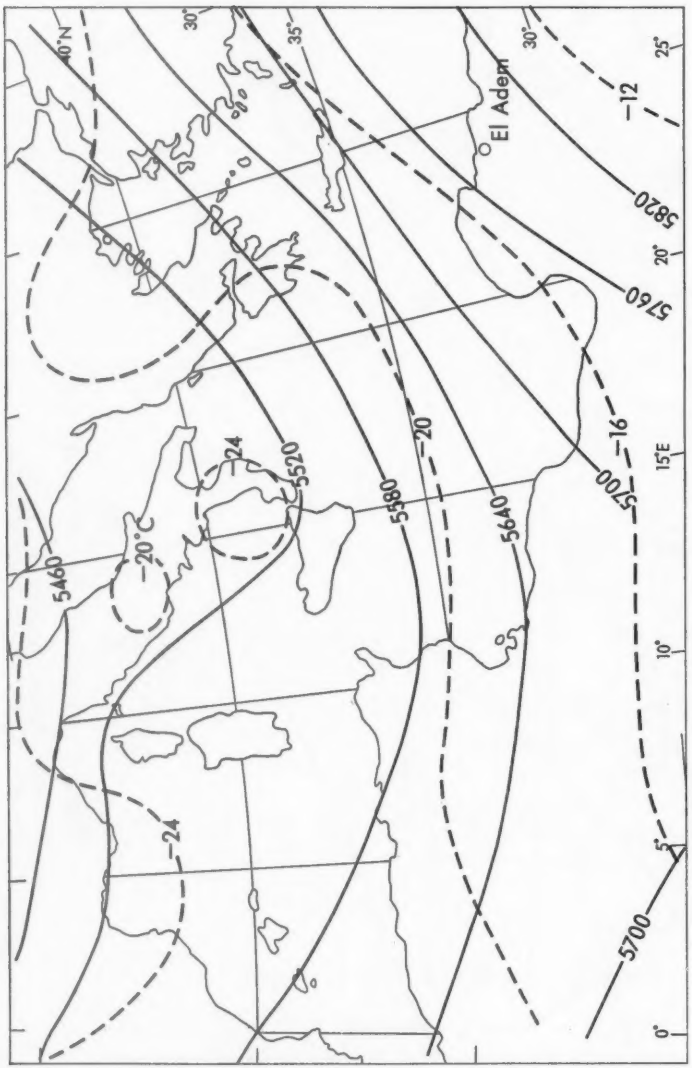

FIGURE 9—500-mb ANALYSIS FOR 00 GMT, 25 MARCH 1966

——— heights in geopotential metres.
- - - - temperatures in degrees Celsius.

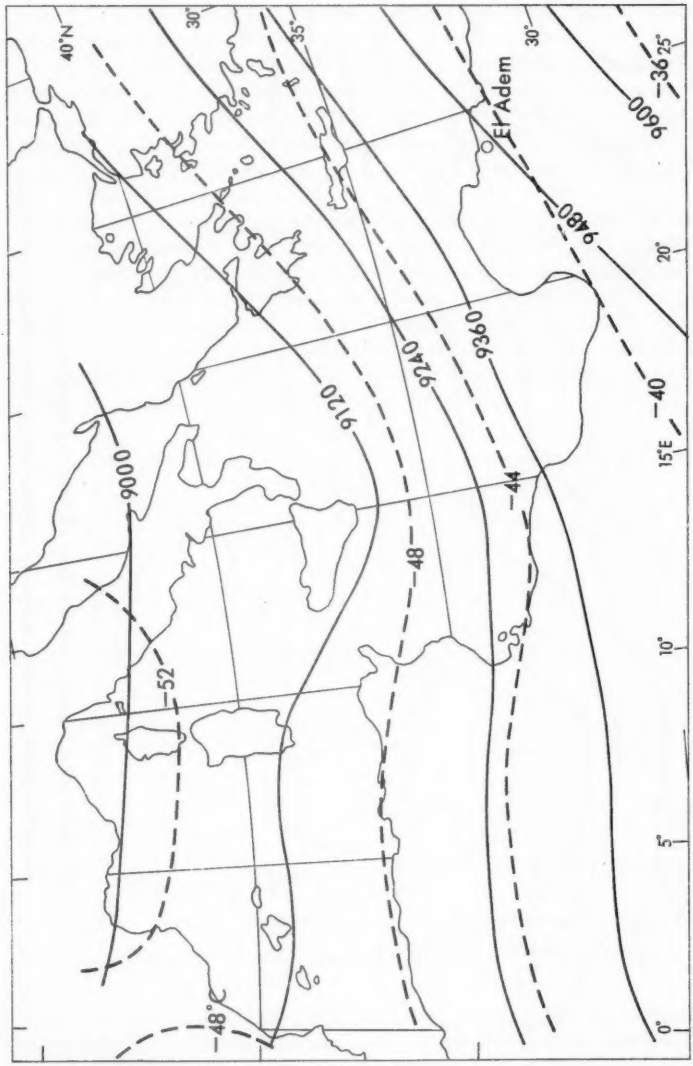

FIGURE 10—300-mb ANALYSIS FOR 00 GMT, 25 MARCH 1966

——— heights in geopotential metres.
- - - - temperatures in degrees Celsius.

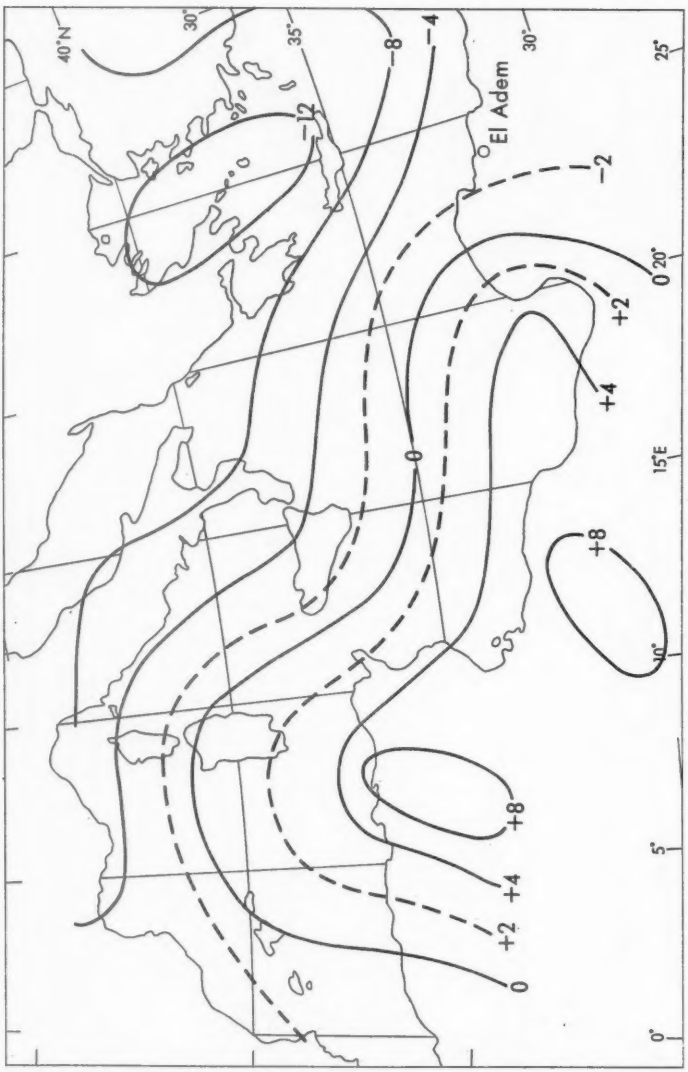

FIGURE 11—ISALLOBARIC CHART FOR 18 GMT, 24 MARCH 1966

Isopleths indicate pressure changes in millibars during the preceding three hours.

Lamb (1954) offered the explanation that possibly a ripple on an old degenerate front could cause a pressure jump, while Tepper (1950) considered that the action of an accelerating cold front, causing a gravity wave to travel ahead of itself at a speed greater than the frontal speed, was analogous to the action of a piston (Freeman, 1948) where the leading edge of the wave becomes almost vertical, thus creating a 'jump'.

In the instance under discussion it seems that there was a series of waves propagated ahead of the cold front. There was also a lowering of the tropopause, and the 850- and 500-mb levels were out of phase. However, pressure jumps can occur in thundery weather and so, because of the scarcity of observations over Libya, it is felt that no firm conclusions can be drawn about the cause of the pressure jumps.

Theoretical values for the period of oscillation for lakes of various shapes, sizes and depths have been derived by several workers, (e.g. Chrystal, 1905), but lack of precise knowledge of all the necessary parameters in practical cases combined with inevitable departures from the simplicity of the theoretical models makes comparisons with observed values generally unrewarding. Oscillations have happened before in Tobruk Harbour, according to the Harbour Master at that time. He said that they happened every year or two but that he had no record of dates of occurrence.

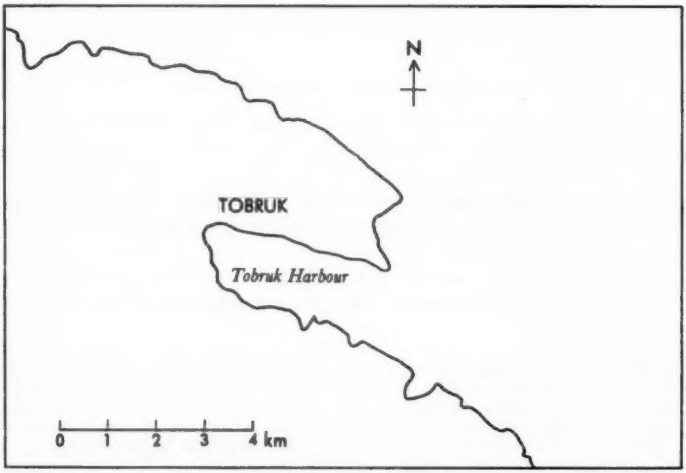

FIGURE 12—MAP SHOWING THE SHAPE OF TOBRUK HARBOUR

Chrystal and others have suggested that seiches can be triggered off by atmospheric disturbances. Seiches occur in lakes, harbours, estuaries, and even over shelving beaches; therefore if it can be accepted that pressure jumps can trigger off seiches, then it becomes important to find a way of forecasting them, particularly in these days of supertankers which often have only one or two metres clearance from the sea bed; seiches superimposed on storm surges may also aggravate flooding.

ACKNOWLEDGEMENT

The author wishes to thank Mr T. H. Kirk, who read a first draft of this article and suggested improvements.

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551.509.323:551.525

A STATISTICAL METHOD OF FORECASTING GRASS-MINIMUM TEMPERATURES AT WEST RAYNHAM

By M. N. PICKUP

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SUMMARY

The variation with wind speed and cloudiness of the difference between screen-minimum and grass-minimum temperatures at West Raynham, Norfolk, was investigated by use of hourly synoptic data from a 10-year period. Mean values of this difference decreased rapidly with increasing wind speed on clear nights, but little variation was found on cloudy nights. There was no significant variation with screen-minimum temperature.

INTRODUCTION

Forecasts of grass-minimum temperatures are required by farmers and horticulturists, expecially in spring and summer when damage to young plants can be avoided provided that sufficient warning can be given.

It is common practice to forecast the minimum screen temperature expected overnight (2100 to 0900 GMT) and then to adjust this figure in the light of the forecast cloud cover and wind strength to give the forecast grass-minimum temperature.

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Craddock and Pritchard (1951) in an investigation based on 16 stations in England found that with light winds the difference (Δ) between the screen-minimum and grass-minimum temperatures averaged 4 deg both for mainly clear and for mainly cloudy nights. For nights with clear skies at Northolt, Saunders (1952) obtained an average value of about 6 deg for Δ for geostrophic wind speeds of 17–24 kn and for wind speeds both below and above this range an average value of about 4–4½ deg. Experience at West Raynham suggests a greater range of Δ and the purpose of this investigation is to obtain values of Δ appropriate to West Raynham.

Data

The data used were the hourly full synoptic observations for West Raynham over the period 1 January 1961–19 March 1970. These were continuous with the exception of the period August 1969 to March 1970 when observations were not made at weekends.

West Raynham lies about 80 m above sea level, some 20 km inland from the northern coast of Norfolk. The airfield is sited on a small plateau and the soil is officially described as 'rather stony loam' which affords good drainage.

The anemometer tower is situated on the roof of the Air Traffic Control building approximately 30 m north of the instrument enclosure. A correction of −10 per cent is made to the recorded wind strength in view of the fact that the height of the cups is 16 m above ground level.

The instrument enclosure is sheltered from the north-west by blast ramps, hangars and other buildings, but freely exposed in other directions.

Method of analysis and results

A total of 3240 nights were examined and of these 639 (19·7 per cent) were classified as 'clear'. A 'clear' night was defined as one with less than 2/8 low and/or medium cloud at each hourly observation between 2100 and 0900 GMT. Nights with cirriform cloud were included but nights with fog were excluded. A further 399 nights (12·3 per cent) were classified as 'cloudy'. A 'cloudy' night was defined as one with 8/8 low and/or medium cloud at each hourly observation between 2100 and 0900 GMT. On 239 of these nights the cloud base was below 2000 ft (approximately 600 m) and on 160 nights the base was above 2000 ft.

For each 'clear' and 'cloudy' night the average surface wind speed and predominant surface wind direction over the period from 2100 to 0900 GMT were obtained. A few nights which showed large variations in wind speed were excluded and also some nights with variable wind directions, but generally the wind direction which predominated was easily selected.

The difference (Δ) between the screen-minimum and grass-minimum temperatures was calculated for each of the 'clear' and 'cloudy' nights. These values of Δ for 'clear' and 'cloudy' nights were studied separately. They were also grouped according to (a) surface wind speeds of 1–5, 6–10, 11–15 and above 15 kn, and (b) surface wind directions in the NE, SE, SW and NW quadrants. For 'cloudy' nights the values of Δ were initially analysed separately for those nights with cloud base above and below 2000 ft, but the values of Δ were found to be similar, and in the final analysis the distinction was not retained. For each combination of wind speed and direction the mean value

of Δ was obtained together with the maximum value, and (for the 'clear' nights only) the standard deviation. Results are shown in Tables I and II for 'clear' and 'cloudy' nights respectively.

A separate analysis was made of Δ on occasions when the screen minimum was near or below 0°C for nights with 'clear' skies and winds less than 10 kn. This sample produced 177 (5 per cent) occasions when the screen minimum was between +1·9°C and −10·0°C. These values were split into four 3-deg intervals, and the mean and standard deviation for Δ in each range are shown in Table III. In addition, the values of Δ with screen minimum between +1·9°C and −6·0°C, 170 occasions, were split into eight 1-deg intervals, and the mean and standard deviation in each range are shown in Table IV.

During this work some notice was taken of other meteorological variables such as humidity, dew and frost. These were not analysed numerically, but they give rise to some of the comments made in the discussion below.

Discussion

Table I ('clear' nights) shows that for all wind directions there is a decrease of the mean value of Δ with increasing wind speed. The same may almost be written of the variability of Δ, but there are exceptions in that as the winds increase from 1–5 to 6–10 kn, the standard deviations increase slightly in the NE and SE sectors, and change very little in the other two sectors. For similar

TABLE I—DEPRESSION (Δ) OF GRASS-MINIMUM TEMPERATURE BELOW SCREEN-MINIMUM TEMPERATURE AT WEST RAYNHAM ON NIGHTS WITH 0–2/8 LOW AND/OR MEDIUM CLOUD

Total number of 'clear' nights 639

	Number of 'clear' nights	Mean difference (Δ)	Standard deviation	Highest Δ
Average wind speed 1–5 knots			*degrees Celsius*	
NE'ly (010–090°)	23	6·1	1·1	7·7
SE'ly (100–180°)	24	5·1	1·0	7·1
SW'ly (190–270°)	38	5·1	1·0	8·0
NW'ly (280–360°)	33	5·3	0·9	7·5
Average wind speed 6–10 knots				
NE'ly	57	3·8	1·3	6·8
SE'ly	82	4·3	1·3	8·6
SW'ly	147	3·5	1·0	6·0
NW'ly	41	3·1	0·8	4·5
Average wind speed 11–15 knots				
NE'ly	22	2·4	0·6	3·4
SE'ly	19	2·0	0·5	2·9
SW'ly	71	2·0	0·4	3·5
NW'ly	23	2·2	0·6	3·4
Average wind speed above 15 knots				
NE'ly	3	1·6	—	1·8
SE'ly	Nil			
SW'ly	50	1·7	0·4	2·8
NW'ly	6	1·7	0·4	2·3

TABLE II—DEPRESSION (Δ) OF GRASS-MINIMUM TEMPERATURE BELOW SCREEN-MINIMUM TEMPERATURE AT WEST RAYNHAM ON NIGHTS WITH 8/8 LOW AND/OR MEDIUM CLOUD

Total number of 'cloudy' nights 399

	Number of 'cloudy' nights	Mean difference (Δ)	Highest Δ
Average wind speed 1–5 knots		*degrees Celsius*	
NE'ly (010–090°)	17	0·7	1·6
SE'ly (100–180°)	4	0·9	1·8
SW'ly (190–270°)	9	0·8	1·6
NW'ly (280–360°)	16	1·1	2·0
Average wind speed 6–10 knots			
NE'ly	43	0·8	2·3
SE'ly	20	0·9	2·6
SW'ly	36	0·9	2·5
NW'ly	18	0·9	1·9
Average wind speed 11–15 knots			
NE'ly	81	0·6	2·2
SE'ly	22	0·9	2·0
SW'ly	33	0·9	1·6
NW'ly	20	0·9	2·0
Average wind speed above 15 knots			
NE'ly	31	0·5	2·0
SE'ly	14	0·7	1·3
SW'ly	29	0·9	2·0
NW'ly	6	0·6	1·0

conditions at Northolt Saunders (1952) obtained mean values of Δ of about 4½ deg, 6 deg, and 4 deg for geostrophic wind speeds of 0–16, 17–24 and over 24 kn respectively, and suggested an explanation of these variations in terms of turbulent mixing. Allowing for the likely difference between surface and geostrophic wind speeds, there is reasonable agreement between the mean value found by Saunders for Δ in his 0–16-kn range, and those found in this investigation, but there is no evidence in the West Raynham results of his temporary increase of mean Δ with increasing wind speed.

The mean and standard deviation of Δ show relatively little change with wind direction. The highest mean value of 6·1 deg is associated with the NE quadrant and the overall maximum of 8·6 deg with the SE quadrant. Light easterly winds which give clear skies over Norfolk are often associated with very dry continental air which may account for the extreme values occurring in these sectors. It was noticed during the investigation that there was a greater fall of ground temperature when the air was dry initially and when subsequently no dew or frost formed. All the highest values of Δ occurred in 'dry' air. The overall maximum of 8·6 deg with a south-easterly wind of 6–10 kn was in fact a borderline case, as the wind overnight averaged 6 kn.

During the analysis it was found that values of Δ between 6·2 deg and 8·6 deg occur each month, with little obvious variation between summer and winter.

It was also noticed that although grass-minimum temperatures officially refer to the period from 2100 to 0900 GMT, large differences between screen and grass temperature often occur before 2100 GMT on occasions of light winds with clear skies. For example on 26 March 1973 (sunset 1824 GMT) the screen temperature at 1900 was 7·4°C and the grass temperature −3·0°C, a difference of 10·4 deg. It is important to remember that such large differences can occur shortly after sunset.

Table II ('cloudy' nights) shows that mean values of Δ are similar for all wind directions and speeds, being generally a little below 1 deg. The maximum values are also rather similar and mostly about 2 deg. In view of the relatively small differences between mean and maximum values, standard deviations were not calculated for this sample. The overall maximum value of 2·6 deg must be slightly suspect, as there can be no guarantee that the cloud did not break during nights when all the hourly observations were of 8/8 cloud.

Tables III and IV were produced to determine whether changes of Δ occur at West Raynham which are similar to those found by Saunders for Northolt on clear winter nights with light winds or calms, Table III having ranges of screen-minimum temperature corresponding to the °F ranges used in Saunders's own Table III, and Table IV having finer subdivisions. Saunders found in such conditions that as the screen-minimum temperature decreases from about +1°C to −8°C, mean values of Δ increased from about 2 deg to 6 deg, and suggested an explanation in terms of latent-heat effects. Both tables indicate that the variation in Δ found at Northolt does not occur at West Raynham, and there is no significant change in either the mean or the standard deviations of Δ around 0°C. Individual values of Δ between 6·3 deg and 8·6 deg were found in all the class intervals of Table IV.

TABLE III—DEPRESSION (Δ) OF GRASS-MINIMUM TEMPERATURE BELOW SCREEN-MINIMUM TEMPERATURE ON 'CLEAR' NIGHTS WITH LIGHT WINDS AT WEST RAYNHAM FOR VARIOUS RANGES OF SCREEN-MINIMUM TEMPERATURES (T_{min})

T_{min} (°C)	+1·9 to −1·0	−1·1 to −4·0	−4·1 to −7·0	−7·1 to −10·0
Number of occasions	73	70	29	5
Mean depression (Δ)	4·3 deg	4·5 deg	3·8 deg	4·4 deg
Standard deviation	1·3 deg	1·5 deg	1·4 deg	1·3 deg

TABLE IV—DEPRESSION (Δ) OF GRASS-MINIMUM TEMPERATURE BELOW SCREEN-MINIMUM TEMPERATURE ON 'CLEAR' NIGHTS WITH LIGHT WINDS AT WEST RAYNHAM FOR A GREATER NUMBER OF NARROWER RANGES OF SCREEN-MINIMUM TEMPERATURE (T_{min})

T_{min} (°C)	+1·9 to +1·0	0·9 to 0·0	−0·1 to −1·0	−1·1 to −2·0
Number of occasions	25	22	26	30
Mean depression (Δ)	4·6 deg	3·9 deg	4·3 deg	4·7 deg
Standard deviation	1·1 deg	1·4 deg	1·3 deg	1·5 deg

T_{min} (°C)	−2·1 to −3·0	−3·1 to −4·0	−4·1 to −5·0	−5·1 to −6·0
Number of occasions	23	17	15	12
Mean depression (Δ)	4·5 deg	4·1 deg	4·2 deg	3·5 deg
Standard deviation	1·3 deg	1·8 deg	1·3 deg	1·4 deg

'Student's'-*t* tests were made on the apparent differences between the mean Δ for West Raynham in Table III, and Saunders's values for corresponding temperature ranges, on the assumptions (i) that Saunders's standard deviations were the same as those in Table III, and (ii) that the ratio of the number of events in each class, used by Saunders and in the present investigation, is a constant—equal to the ratio of the lengths of the two periods considered, i.e. two winters by Saunders to 10 winters here. Results of these *t*-tests indicate (i) that for the first temperature range there is less than 1 chance in 100 of such a large mean difference arising by accident of the samples if there is really no difference in behaviour at the two sites; (ii) that for the third temperature range there is about a 6 per cent chance of finding such a large mean difference by accident of the samples; and (iii) that for the other temperature ranges the apparent differences could easily arise by chance.

It was noted during nights when there were breaks in the cloud for periods of even one or two hours that rapid falls of ground temperature could occur. Nights with variable cloud were not analysed objectively, but for such nights with moderate wind Δ is about 2 deg.

Conclusions

For 'clear' nights the mean value of Δ for West Raynham decreases rapidly with increasing surface wind speed from 5 to 6 deg for light winds to about 1½ deg for winds above 15 kn. It shows little variation with wind direction. The standard deviation of Δ decreases from about 1 deg for surface winds up to 10 kn to about 0·5 deg for stronger winds. Maximum values of Δ within the range 6·2 to 8·6 deg occur each month (with winds less than 10 kn) with little variation between summer and winter.

For cloudy nights the mean value of Δ is similar for all wind speeds and directions, being in general a little below 1 deg. Maximum values of Δ for such nights are mainly within the range 1·5 to 2·5 deg.

For 'clear' nights with light winds the variation in Δ with screen-minimum temperatures near or below 0°C which Saunders detected in the winter at Northolt is not apparent at West Raynham. For such conditions a mean value of Δ of 4·3 deg is appropriate at West Raynham.

During nights when there are breaks in the cloud for periods of even one or two hours, rapid falls of ground temperature occur, especially with light winds. On occasions of light winds with clear skies large differences between screen and grass temperatures can occur shortly after sunset, for example a difference of 10·4 deg within one hour of sunset on 26 March 1973.

Acknowledgement

The author would like to thank Mr C. L. Hawson for help in the preparation of this paper.

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MEETING REPORT—SEVENTH INTERNATIONAL LASER RADAR CONFERENCE, PALO ALTO, CALIFORNIA, 4–7 NOVEMBER 1975

By R. E. W. PETTIFER

The Seventh International Laser Radar Conference was a highly successful meeting for which nearly two hundred scientists from all over the western world gathered at the Stanford Research Institute in Palo Alto, California. Unfortunately the Russian and other east European contributors did not attend and their papers were read by title only: a sad omission from the program. Nevertheless, the fact that laser radar techniques are now firmly established as fruitful means of atmospheric investigations at levels up to 100 km was evidenced by the crowded and comprehensive program in which more than 70 papers were presented.

The main emphasis of the meeting was on the development of new laser techniques or the improvement or extension of existing laser methods for atmospheric studies. Professor R. M. Schotland outlined an interesting development of the Doppler laser radar concept in which the use of two nearly equal output frequencies leads to detection of a signal at their difference frequency. Since this difference frequency will be of the order of kilohertz or megahertz rather than the gigahertz of the output laser frequency, there is a consequent relaxation in the band-width and frequency-stability requirements in the detectors.

There was considerable emphasis on the detection of gaseous trace constituents in the troposphere, especially pollutants in the boundary layer, by the Differential Absorption and Scattering technique (DASE, also called DIAL or DISC) which seems to have gained favour over the less sensitive, though technically more straightforward, vibrational Raman method. The bulk of the work reported using the DASE technique had been directed to the detection of tropospheric water vapour, and although the theory and feasibility of the work was demonstrated over a wide range of wavelengths in the red and infra-red, no new atmospheric measurements were presented. The applications of the technique to the measurement of pollutants such as SO_2 and HCl in effluent from various sources and even of naturally occurring stratospheric OH were also discussed.

Two complementary papers on the signal-induced noise effects in certain photomultipliers produced some lively discussion between groups of believers and unbelievers, but there seems to be emerging a weight of evidence to support the existence of these effects in many different types of photomultiplier.

A long session of the meeting was devoted to the results of observations of stratospheric aerosols, a topic of especial relevance in 1975 following the Fuego Volcano eruption in 1974. Some interesting correlations between the characteristics of the well-marked dust layer and other stratospheric parameters were illustrated. For example, work by NASA scientists under the leadership of Dr M. P. McCormick has shown that the level of the peak in the ratio between backscatter from the dust and from the air at the same level was well correlated with the level of minimum temperature of the stratosphere, that the vertical extent of the dust layer was associated with the vertical extent of a

layer of air colder than the average stratospheric temperature, and that increases in the mass loading of the dust layer were correlated with increases in the minimum or average stratospheric temperature. Many other topics concerning stratospheric aerosol were discussed, including most likely formation mechanisms, transport processes, a marked correlation of aerosol concentration with decreases in maximum ozone amount at the ozone peak, and deductions about size distributions and refractive index. There were two presentations of novel approaches to stratospheric work. In one, Dr J. Reagan and his colleagues at the University of Arizona, Tucson described a very comprehensive experiment involving simultaneous measurements using bi-static lidar and a seven-channel tracking solar radiometer. In the other, Dr R. E. W. Pettifer of the Meteorological Office presented results of the difficult but potentially useful technique utilizing the vibrational Raman scattering from nitrogen to obtain air-density measurements that are unaffected by the presence of aerosols and from which the first stratospheric temperature profiles obtained by laser radar methods have been derived. He also presented the results of a two-wavelength Rayleigh/Mie backscattering experiment that is free from the ambiguities introduced into single-wavelength experiments by the normalization process.

A new development at the conference was the devotion of a complete session to meteorological observations by lidar. This group of papers served to illustrate that such techniques are still in their infancy. However, it included a description of a comprehensive 'present-weather' monitoring system that has been built and which, it is hoped, will yield information in real time on visibility and on precipitation type and rate. Several papers dealing with remote measurements of wind or turbulence were presented, including the preliminary results of investigations into the dynamical structure of dust devils. Horizontal and slant visual range experiments were also discussed.

The very extensive work in progress at the Stanford Research Institute and at the University of Arizona on the nature and dynamics of the tropospheric aerosols, especially in the boundary layer, was illustrated in a series of papers from these two sources. From the work at Tucson, a good fit to the laser scattering results was obtained by fitting a two-component Bode model aerosol distribution with a real refractive index of 1·4 in a particle-size range of from 0·02 μm to 5 μm. Similar boundary-layer work at NOAA was reported, in which a two-component log-normal size distribution with peaks at 10^{-1} μm and 50 μm was postulated. Additional tropospheric work reported included the study of the development of snow precipitation from a cloud consisting initially of two well-separated regions, one of liquid drops, the other of ice crystals; attempts to measure rainfall rate by a single-ended backscatter lidar, and an extensive study of the relationships between backscatter and extinction in fogs.

The conference concluded with two sessions on theoretical scattering studies involving the effects of irregularly shaped particles and spherical aerosols. It is clear from the work reported that the complications of irregularity in particle shape are as yet not being fully accounted for in most laser radar work, and the result, announced by Dr G. Grams of NCAR, that backscatter from non-spherical particles can be as much as one order of magnitude less than from equivalently sized spheres, is an indicator of the possible extent of the problem.

It is clear from the vigorous character of this valuable and interesting meeting that the use of lasers for a wide range of atmospheric sounding experiments is

now an established and expanding field from which in the next decade a great deal of data on the nature of the atmosphere, its structure, composition and small-scale dynamics may be expected.

REVIEWS

Climate in a small area, by Masatoshi M. Yoshino. 265 mm × 190 mm, pp. xvi + 549, *illus.*, International Book Distributors Ltd, 66 Wood Lane End, Hemel Hempstead, Herts. HP2 4RG, 1975. Price: £16.

The volume under review is a revised and enlarged version, written in English, of a work in Japanese which appeared in 1961. In its declared scope, layout and approach, it calls to mind Geiger's classic *Climate near the ground*, which first appeared in 1927 and is now in its fourth edition (Harvard University Press, 1965). A review may therefore profitably take the form of a comparison of the two books.

The complex interaction of local topography, ground surface conditions and prevailing weather which gives rise to the climate experienced over a particular small area probably dictates that any account of the subject shall be rather fragmented. It is always much more difficult to present a coherent unified theory than to quote specific examples (of, say, valley winds or frost-pocket temperatures). Both books suffer from this difficulty, but Yoshino succeeds in sifting out gratuitous detail from his examples, which allows a clearer picture to emerge. Also, the chapters of the new book are subdivided much more explicitly and so, with better indexing than Geiger, it is possible to trace topics much more easily.

There is a slight difference in the space scales of the phenomena described by the two authors. Geiger's range can perhaps be considered to be 10^{-2} to 10^{4} m, whereas Yoshino's is somewhat higher (say, 10^{1} to 5×10^{4} m). Yoshino omits what might be called 'agricultural micro-climatology' (Geiger devotes a whole chapter to the air layer near plant-covered ground), but gives very extensive coverage to phenomena at the larger-scale end of the 'local climate' range. His chapter on 'Local airstreams and weather' occupies 130 pages and includes many examples of local climatic effects having space scales of tens of kilometres and their relationship with conditions on the synoptic scale. Japanese examples, naturally, provide the bulk of the material, but many European, American and Russian cases are also quoted and discussed. The section on local winds is particularly comprehensive. Yoshino also gives much wider coverage than Geiger in the field of urban climate, where there has been a considerable increase in both observational and theoretical studies over the last decade.

In the final chapter, examples are given of the importance of local climate for plant ecology (particularly the influence of wind on tree growth) and geomorphology (including erosion due to wind, rain and ice).

The book is well presented, with clear diagrams and the written style is generally good. There is the occasional quaintness of expression which inevitably arises from an author working in a second language (for example, in one diagram, four categories of frost risk are defined as '(a) frequent frost, (b) frost once or twice a year, (c) frost experienced once or twice by old men, (d) frost is rare').

The wealth of detail in Geiger's work and his constant awareness of the basic physical processes at work in local climate make it difficult to imagine his volume ever being completely replaced. The value in Yoshino's book lies chiefly in its more up-to-date presentation style, its condensation of the results of more recent observational studies and its revelation of the considerable amount of investigational work on local climate undertaken in Japan, not formerly accessible because of the language barrier.

J. S. HOPKINS

The structure of turbulent shear flow (second edition) by A. A. Townsend. 230 mm × 170 mm, pp. xi + 429, *illus.*, Cambridge University Press, Bentley House, 200 Euston Road, London NW1 2DB, 1975. Price: £15.50.

This second edition of Townsend's well-known book is a complete revision of the original monograph, which was published in 1956, and comparison with the previous edition is inevitable. The current edition covers material up to about 1973, and the enormous amount of work on turbulent shear flows in the intervening years is evidenced by the increased length of the bibliography. The book itself is more than 100 pages longer, and contains a completely new chapter on turbulent convection. The author describes many modern theories of turbulent flows, and assumes familiarity with the basic ideas and mathematics of fluid mechanics, so the book is most likely to be of use in postgraduate research.

Some of the additional pages are due to a more detailed derivation of the basic equations and general properties of turbulent flow. The first four chapters give a clear description of such statistical quantities as correlation functions and energy spectra, and how they are related to the structure of the flow. The development of a field of turbulence under very simple external conditions is also presented here, and it is a pity that, while most of the initial sections are very thorough, the treatment of the so-called 'rapid-distortion' theory is somewhat hurried. This theory, which describes the response of a turbulent fluid to a rapid strain is one of the few analytic theories which really predict the structure of the turbulence, and is well supported by experimental results. As such, the results of the theory are often used elsewhere in the book to provide some physical foundation for semi-empirical flow calculations. The description of rapid distortion is more complete in the first edition, and two figures, 3·9 and 3·10, are simply reproduced from the first edition without defining anywhere in the text the quantities plotted.

The rest of the book is devoted to particular types of flow, namely pipe and channel flow, free turbulent flow, boundary layers and wall jets, turbulent convection, and curved streamline flow. These chapter subjects are the same as the first edition, with the exception of the chapter on convection. They all consist of a number of fairly short sections, and describe a very large amount of experimental and theoretical work. Together with the full bibliography, this makes the book very valuable as a reference work, although difficulties with notation and a few confusing misprints may possibly cause problems in one or two isolated cases.

There are a number of meteorological applications in the book, in spite of there being only five pages describing the turbulent Ekman layer. The atmospheric surface layer, or constant-stress layer, is discussed in the general context of turbulent wall layers, and the sections concerned with the dynamical effects of heat have many applications in meteorology and oceanography. A great deal of work from the fields of geophysics, engineering, and aerodynamics is brought together in this book, and presented in a way that brings out the basic similarities and underlying structures of the flows.

The author succeeds in giving the reader some real feeling for what a turbulent fluid looks like and how it behaves in various circumstances. Some understanding of the structure of the flow is necessary before useful semi-empirical theories can be developed, and many such models are analysed in terms of their underlying assumptions, the justification for the assumptions, and also their limitations. The presentation of the mathematical models is mostly very lucid, and gives an insight into the process involved in constructing an empirical theory. Anyone concerned with the theory of turbulence in the atmospheric boundary layer would certainly find the book illuminating and useful.

R. I. SYKES

OBITUARY

It is with regret that we have to announce the death of Mr F. W. Ward, Senior Scientific Officer, Preston, on 3 December 1975.

CORRECTIONS

Meteorological Magazine, January 1976, p. 27, Figure 1. The labelling of the axes implies that decreases of temperature and humidity with increasing height correspond to negative lapse rates, which is incorrect; the signs of the numbers labelling both axes should therefore be reversed.

Meteorological Magazine, February 1976, p. 64. The eighth line from the foot of the page should read 'or within -3σ to -2σ of Ratcliffe's mean value of 510 dam . . . '.

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NOTICES

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